



Fermi National Accelerator Laboratory

**FERMILAB Pub-94/049-E
E687**

Measurement of the Form Factors for the Decay $D_s^+ \rightarrow \phi \mu^+ \nu$

P.L. Frabetti et al
The E687 Collaboration

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

February 1994

Submitted to *Physics Letters B*

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Measurement of the Form Factors for the Decay $D_s^+ \rightarrow \phi \mu^+ \nu$

P. L. Frabetti

Dip. di Fisica dell'Università and INFN - Bologna, I-40126 Bologna, Italy

H. W. K. Cheung [a], J. P. Cumalat, C. Dallapiccola [b], J. F. Ginkel, S. V. Greene,

W. E. Johns, M. S. Nehring

University of Colorado, Boulder, CO 80309, USA

J. N. Butler, S. Cihangir, I. Gaines, P. H. Garbincius, L. Garren, S. A. Gourlay,

D. J. Harding, P. Kasper, A. Kreymer, P. Lebrun, S. Shukla, M. Vittone

Fermilab, Batavia, IL 60510, USA

S. Bianco, F. L. Fabbri, S. Sarwar, A. Zallo

Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

R. Culbertson, R. W. Gardner, R. Greene, J. Wiss

University of Illinois at Urbana-Champaign, Urbana, IL 61801

G. Alimonti, G. Bellini, B. Caccianiga, L. Cinquini [c], M. Di Corato, M. Giammarchi,

P. Inzani, F. Leveraro, S. Malvezzi [d], D. Menasce, E. Meroni, L. Moroni, D. Pedrini,

L. Perasso, A. Sala, S. Sala, D. Torretta [a]

Dip. di Fisica dell'Università and INFN - Milano, I-20133 Milan, Italy

D. Buchholz, D. Claes [e], B. Gobbi, B. O'Reilly,

Northwestern University, Evanston, IL 60208, USA

J. M. Bishop, N. M. Cason, C. J. Kennedy [f], G. N. Kim [g], T. F. Lin, D. L. Pusejic,

R. C. Ruchti, W. D. Shephard, J. A. Swiatek, Z. Y. Wu

University of Notre Dame, Notre Dame, IN 46556, USA

V. Arena, G. Boca, C. Castoldi, G. Gianini, S. P. Ratti, C. Riccardi, P. Vitulo

Dip. di Fisica Nucleare e Teorica and INFN - Pavia, I-27100 Pavia, Italy

A. Lopez, University of Puerto Rico at Mayaguez, Puerto Rico

G. P. Grim, V. S. Paolone, P. M. Yager, University of California-Davis, Davis, CA 95616

J. R. Wilson, University of South Carolina, Columbia, SC 29208

P. D. Sheldon, Vanderbilt University, Nashville, Tenn., TN 37235 USA

F. Davenport, University of North Carolina-Asheville, Asheville, NC 28804

J. F. Filaseta, Northern Kentucky University, Highland Heights, KY 41076

G.R. Blackett, M. Pisharody, T. Handler

University of Tennessee, Knoxville, TN 37996 USA

B. G. Cheon, J. S. Kang, K. Y. Kim

Korea University, Seoul 136-701, Korea

(E687 Collaboration)

Abstract

Fermilab high-energy photoproduction experiment E687 provides a sample of approximately 90 events of the decay mode $D_s^+ \rightarrow \phi \mu^+ \nu$. The ratios of the form factors governing the decay are measured to be $R_v = 1.8 \pm 0.9 \pm 0.2$ and $R_2 = 1.1 \pm 0.8 \pm 0.1$, implying a polarization of $\Gamma_l/\Gamma_t = 1.0 \pm 0.5 \pm 0.1$ for the electron decay, consistent with our measurement of the form factors for the decay $D^+ \rightarrow \bar{K}^{*0} \mu^+ \nu$.

We report on an analysis of 90 ± 12 events of the decay mode $D_s^+ \rightarrow \phi \mu^+ \nu$ (charge conjugates are implied). The data were collected in the photoproduction experiment E687, conducted in the Fermilab Wideband Photon beam during the 1990-1991 fixed-target run.

The form factors for this decay are expected [1] to be similar to those for the decay $D^+ \rightarrow \bar{K}^{*0} l^+ \nu$ which are well measured [2] [3] [4]. Initial interest in the D_s^+ form factors developed when the first experimental measurement appeared to disagree with this prediction [5].

The E687 detector [6] studies high-energy photon-Beryllium interactions using a multi-particle magnetic spectrometer with excellent vertex measurement, particle identification, and calorimetric capabilities. The average triggered photon energy is approximately 220 GeV. The trigger requires evidence of tracks outside the region where Bethe-Heitler pairs are produced and a minimum energy of approximately 45 GeV in our hadronic calorimeter. Charged particles emerging from the experimental target are tracked through a twelve-plane silicon microstrip vertex detector, an analysis magnet, three stations of multiwire proportional chambers, a second analysis magnet, and two more multiwire proportional chambers. The vertex detector measures decay proper times with approximately 0.048 ps resolution for charm particles which decay with all daughters detected in the microstrips. Three Čerenkov counters with different thresholds allow kaons to be separated from pions over a momentum range from 4.5 to 61 GeV/c. Particle tracks are projected through the inner electromagnetic calorimeter, hadron calorimeter, and additional shielding and are matched to hits in the inner muon detector consisting of three planes of scintillators and four planes of 5.08 cm diameter proportional tubes, covering approximately ± 40 mrad.

The data were reconstructed and then skimmed by requiring evidence of detached vertices in the event. Specifically, all high-quality two-track vertices were formed and the event was accepted if any two vertices were separated by more than 4.5σ , where σ is the error on the separation of the two-track vertices.

In this analysis, all tracks are searched for correct sign, mass, lepton and Čerenkov identification combinations to form $KK\mu$ candidates. All tracks must be found in the microstrips and the PWC system. The muon is identified in the inner muon detector where

it must leave hits in at least three of the seven planes if the momentum is less than 30 GeV/c, and at least five of the seven planes if the momentum is greater than 30 GeV/c. The kaons must be identified by the Čerenkov system as kaon definite or kaon-proton ambiguous.

We require the $KK\mu$ combination to form a good vertex with a confidence level greater than 20%. Background from $D_s^+ \rightarrow KK\pi$, where the pion is misidentified as a muon (about 1% probability), is eliminated by requiring that the reconstructed $KK\mu$ mass be less than 1.9 GeV/c². To avoid possible contamination from diffractively photoproduced ϕ 's, we require that the value of p_\perp^2 for the ϕ with respect to the incident photon direction exceeds 0.05 GeV²/c².

The primary tool for eliminating non-charm backgrounds is to require a statistically significant detachment of the secondary vertex from the primary, production vertex. We find the primary vertex by searching for the most upstream high-quality vertex in the target region that can be made from the tracks which remain after the $KK\mu$ combination is removed. The resulting primary vertex will contain two or more tracks. The distance between the primary and the secondary vertices is ℓ , its measurement error is σ_ℓ , and we require a detachment of $\ell/\sigma_\ell > 3$.

Finally, we require that the $KK\mu$ vertex be isolated from other tracks in the event (not including tracks in the primary vertex) by requiring that the maximum confidence level for another track to form a vertex with the candidate be less than 10%. Figure 1 shows the KK invariant mass distribution for candidates which pass all cuts.

To fit for the form factors, we use the matrix element form and methodology found in [2] and calculate the kinematic variables: $\cos\theta_\nu$, the cosine of the angle between K_a and the D_s direction in the ϕ rest frame, $\cos\theta_l$, the cosine of the angle between the ν and the D_s direction in the $\mu\nu$ rest frame, t , the square of the $\mu\nu$ mass and χ , the angle between the KK and $\mu\nu$ planes in the D_s rest frame defined as the angle between $\vec{K}_b \times \vec{K}_a$ and $\vec{\mu} \times \vec{\nu}$. K_a may be either the K^+ or the K^- and K_b is the other kaon. D_s^+ and D_s^- decays have the same definition of variables and no change is required in the matrix element.

We assume that the reconstructed D_s momentum vector points along the line defined

by the primary and secondary vertex. This leaves a two-fold kinematic ambiguity and we use the solution that gives the lower D_s momentum which yielded slightly better estimates for the kinematic variables in Monte Carlo studies. Due to finite resolution, a significant fraction of events are reconstructed outside physical limits (the p_\perp of the charged daughters relative to the D_s direction implies the decay of a particle with a mass larger than the D_s mass). These events are recovered by moving the primary vertex to the nearest physically allowed solution and recomputing the kinematic variables. Monte Carlo studies show that the inclusion of the recovered events does not significantly degrade the resolution of the four kinematic variables. We find that requiring that the reconstructed event be physical or nearly physical does not significantly improve signal to noise.

To fit for the form factors we use the method found in [2] and [7] with one exception: we subtract the likelihood of events in the ϕ sidebands * which avoids parameterizing the background. The result of the sideband subtraction is 90 ± 12 signal events. This modified continuous likelihood method maximizes the fit parameters by maximizing the weights of Monte Carlo events that are kinematically near each data event. The method naturally includes the effects of resolution, acceptance, and efficiency. A Monte Carlo event is considered near to a data event if it is less than $1/20$ of the kinematic range from the data point in each dimension. The fit result is not sensitive to the exact choice of this definition.

We fit to $\cos \theta_v$, $\cos \theta_l$, t/t_{max} , and χ . In the absence of lepton mass effects, there are two axial and one vector form factor, $A_1(t)$, $A_2(t)$, and $V(t)$. We assume these form factors have a single pole dependence with masses $M_A = 2.5$ GeV and $M_V = 2.1$ GeV [2], and fit for the ratio of the form factors evaluated at $t = 0$: $R_v = V(0)/A_1(0)$ and $R_2 = A_2(0)/A_1(0)$. When all effects of the finite muon mass [8] are included, as we do in our fit, a third form factor ratio appears, R_3 . We set this form factor ratio to zero and we are not sensitive to

*Using $1.0195 \text{ GeV}/c^2$ as the ϕ mass and $3 \text{ MeV}/c^2$ as Δ , we take the signal region as $\pm 2\Delta$ and the sidebands as $-6\Delta \rightarrow -4\Delta$ and $4\Delta \rightarrow 6\Delta$.

this assumption.

The statistical errors returned by the fit include the effects of resolution, including the two-fold ambiguity. They do not include the effects of fluctuations in the subtracted background likelihood. We estimate this effect by fitting many samples of Monte Carlo with background and find that the errors are underestimated by 30%. Our statistical errors in this paper have been corrected for this effect. Many analytic and Monte Carlo checks were performed to confirm our reported errors.

The systematic error includes the change in the fit result when we subtract the expected backgrounds [9] from decay modes with a ϕ and another particle misidentified as a muon. We assume that decay modes with a ϕ and a μ are negligible. We include the effect of non-Gaussian tails as measured by the fitting of many Monte Carlo samples. The systematic error also includes the uncertainty due to local variations in the muon identification efficiency and uncertainty in the triggering energy.

Figure 2 compares the data with the distribution of a Monte Carlo weighted with the fit results. We find $R_\nu = 1.8 \pm 0.9 \pm 0.2$ and $R_2 = 1.1 \pm 0.8 \pm 0.1$. R_ν and R_2 have a correlation coefficient of +20%. To facilitate comparisons to other measurements, we report the polarization for the electron decay, *i.e.* we set the lepton mass to the mass of the electron and integrate over the appropriate parts of the matrix element. The polarization for these values of R_ν and R_2 is $\Gamma_l/\Gamma_t = 1.0 \pm 0.5 \pm 0.1$.

In Table I we compare our measurement of the form factors in the semileptonic decay $D_s^+ \rightarrow \phi \mu^+ \nu$ to the only other measurement of the $D_s^+ \rightarrow \phi \mu^+ \nu$ form factors [5] and our $D^+ \rightarrow \bar{K}^{*0} \mu^+ \nu$ form factors [4]. We note that the lower-statistics E653 D_s measurement has errors comparable to our D_s measurement and that our D_s errors scale roughly as $1/\sqrt{N}$ from our D^+ errors. Although we do not contradict the E653 measurement of the D_s form factors, our values are consistent with our measurement of the D^+ form factors.

We wish to acknowledge the assistance of the staffs of the Fermi National Accelerator Laboratory, the INFN of Italy, and the physics departments of the collaborating institutions. This research was supported in part by the National Science Foundation, the

U.S. Department of Energy, the Italian Istituto Nazionale di Fisica Nucleare and Ministero dell'Università e della Ricerca Scientifica e Tecnologica, and the Korean Science and Engineering Foundation.

REFERENCES

- ^a Present address: Fermilab, Batavia, IL 60510, USA.
- ^b Present address: University of Maryland, College Park, MD, 20742, USA
- ^c Present address: University of Colorado, Boulder, CO 80309, USA
- ^d Present address: Dip. di Fisica Nucleare e Teorica and INFN - Pavia, I-27100 Pavia, Italy
- ^e Present address: University of New York, Stony Brook, NY 11794, USA.
- ^f Present address: Yale University, New Haven, CN 06511, USA.
- ^g Present address: Pohang Accelerator Laboratory, Pohang, Korea.
- ¹ C.W. Bernard, A.X. El-Khadra, and A. Soni, Phys. Rev. D 45 (1992) 869.
V. Lubicz, G. Martinelli, M.S. McCarthy, and C.T. Sachrajda, Phys. Lett. B 274 (1992) 415.
- ² E691 Collab., J. C. Anjos et al., Phys. Rev. Lett. 65 (1990) 2630.
- ³ E653 Collab., K. Kodama et al., Phys. Lett. B 274 (1992) 246.
- ⁴ E687 Collab., P. L. Frabetti et al., Phys. Lett. B 307 (1993) 262.
- ⁵ E653 Collab., K. Kodama et al., Phys. Lett. B 309 (1993) 483.
- ⁶ E687 Collab., P. L. Frabetti et al., Nucl. Instrum. Methods. A320 (1992) 519.
- ⁷ D. M. Schmidt, R. J. Morrison, M. S. Witherell, Nucl. Instrum. Methods. A328 (1993) 547.
- ⁸ J.G. Korner and G.A. Schuler, Z. Phys. C 46 (1990) 93.
- ⁹ E687 Collab., P. L. Frabetti et al., Phys. Lett. B 313 (1993) 253.

FIGURES

FIG. 1. The a) K^-K^+ mass for $D_s^+ \rightarrow \phi\mu^+\nu$ candidates with $\ell/\sigma_\ell > 3$. The solid line is a fit to the distribution. Due to the mass cuts defining the signal region, 90 signal events are used in the form factor fit.

FIG. 2. Form factor fit projections: a) $\cos\theta_v$ for $t/t_{max} < 0.5$, b) $\cos\theta_v$ for $t/t_{max} > 0.5$, c) $\cos\theta_l$ for $t/t_{max} < 0.5$, d) $\cos\theta_l$ for $t/t_{max} > 0.5$, e) χ/π for $\cos\theta_v < 0$, f) χ/π for $\cos\theta_v > 0$, g) t/t_{max} . The data is shown as the points with error bars, the weighted Monte Carlo is shown as the histograms.

TABLES

TABLE I. Form Factor Measurements

	signal background		R_v	R_2	Γ_ℓ/Γ_t
This paper	90	33	$1.8 \pm 0.9 \pm 0.2$	$1.1 \pm 0.8 \pm 0.1$	$1.0 \pm 0.5 \pm 0.1$
E653 [5]	19	5	$2.3^{+1.1}_{-0.9} \pm 0.4$	$2.1^{+0.6}_{-0.5} \pm 0.2$	$0.54 \pm 0.21 \pm 0.10$
E687 ($D^+ \rightarrow \bar{K}^{*0} \mu^+ \nu$) [4]	866	130	$1.74 \pm 0.27 \pm 0.28$	$0.78 \pm 0.18 \pm 0.10$	$1.20 \pm 0.13 \pm 0.13$

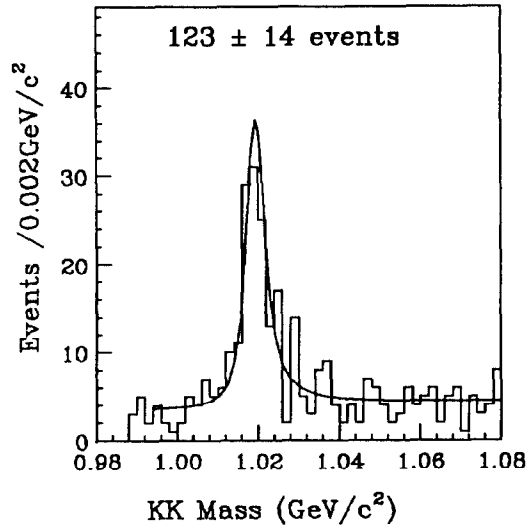


FIG. 1. The K^-K^+ mass for $D_s^+ \rightarrow \phi\mu^+\nu$ candidates with $\ell/\sigma_\ell > 3$. The solid line is a fit to the distribution. Due to the mass cuts defining the signal region, 90 signal events are used in the form factor fit.

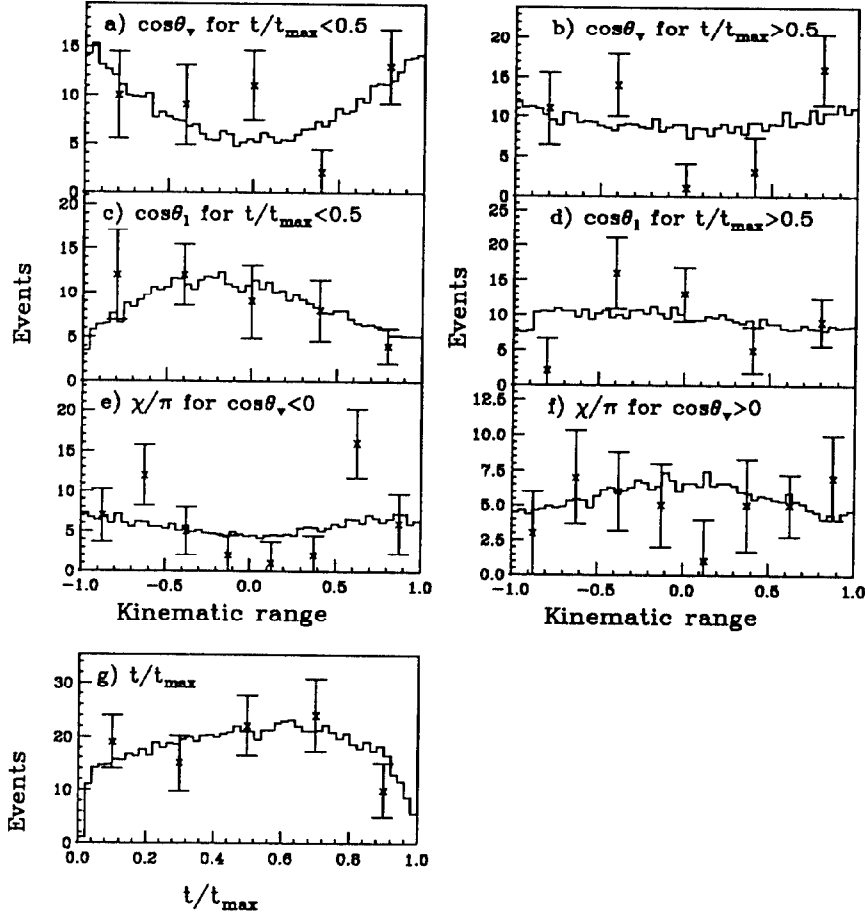


FIG. 2. Form factor fit projections: a) $\cos \theta_v$ for $t/t_{max} < 0.5$, b) $\cos \theta_v$ for $t/t_{max} > 0.5$, c) $\cos \theta_l$ for $t/t_{max} < 0.5$, d) $\cos \theta_l$ for $t/t_{max} > 0.5$, e) χ/π for $\cos \theta_v < 0$, f) χ/π for $\cos \theta_v > 0$, g) t/t_{max} . The data is shown as the points with error bars, the weighted Monte Carlo is shown as the histograms.